Abundance Estimate of the Gulf of Maine Harbor Porpoise

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ABSTRACT

Shipboard surveys were conducted in the summer of 1991 to estimate the abundance of harbor porpoises, *Phocoena phocoena*, in the northern Gulf of Maine and lower Bay of Fundy. The best estimate is 37,500 (95% CI: 26,600 to 86,400). The estimate is based on the independent team sighting procedure from one ship, which allowed the estimation of $g(0)$: 0.72 (SE=0.06). The abundance estimate presented is substantially higher than previous estimates for the area. This is due to the more extensive areal coverage and the inclusion of $g(0)$ into the estimate. While the statistical precision that was reported here included some sources of uncertainty, others remain to be addressed. The most important of these are the potential downward bias due to animals avoiding the vessel, the highly aggregated spatial distribution of porpoises and the largely unknown effects of heterogeneity of observers, platforms and environmental conditions.

KEYWORDS: HARBOUR PORPOISE; NORTH ATLANTIC; SURVEY-SHIP; ASSESSMENT; $g(0)$.

INTRODUCTION

There are five past surveys that estimated the abundance of harbor porpoise in the Gulf of Maine-Bay of Fundy region (Gaskin, 1977; Prescott *et al.*, 1981; Winn, 1982; Kraus *et al.*, 1983b; Gaskin *et al.*, 1985). Estimates ranged from roughly 3,000 to 15,000 animals. They provided minimum estimates of abundance because of their limited ranges and because of failures of assumptions made in the analyses. In 1991, two surveys were conducted over a much broader area using line transect survey techniques developed to overcome some of the previous methodological problems (Kraus *et al.*, 1983a; Barlow, 1988; Butterworth and Borchers, 1988; Polacheck, 1989; 1994a; b; Polacheck and Smith, 1989; 1990; Øien, 1990; Polacheck and Thorpe, 1990; Polacheck *et al.*, 1990; 1994).

In this paper, I present a new population abundance estimate using data collected during the two 1991 surveys. The reliability of the abundance estimate is assessed and potential sources of uncertainties that were not accounted for are discussed. This paper updates the abundance estimate reported in Smith *et al.* (1991), Anon. (1992) and Read *et al.* (1993).

METHODS

Field procedures

From 22 July – 31 August 1991, a shipboard sighting survey was performed in the offshore waters of the Gulf of Maine-lower Bay of Fundy-southern Scotian shelf area. From 3 – 17 August 1991 a second survey was performed in the shallow inshore bays off Maine (Fig. 1). 'Passing mode' line transect methods (Burnham *et al.*, 1980; Butterworth and Borchers, 1988) were used on both vessels. The independent team sighting procedure was used on

one of the ships to allow the estimation of $g(0)$, the probability of detecting a group of animals on the trackline.

The survey area was stratified first by depth, then within the deeper, offshore region by expected harbor porpoise density. This resulted in four strata, referred to as the 'high density', 'intermediate density', 'low density' and the shallower 'inshore' strata (Fig. 1). The abundance estimates for the high, intermediate and low density strata were obtained from data collected aboard the *R/V Abel-J* (106-ft, 15-ft draft). The abundance estimate for the inshore stratum was obtained from data collected aboard both vessels because the *R/V Abel-J* could not enter all of the shallow inshore bays and the smaller vessel, *M/V Sneak Attack* (48-ft, 4-ft draft), could not accommodate the independent team sighting procedure.
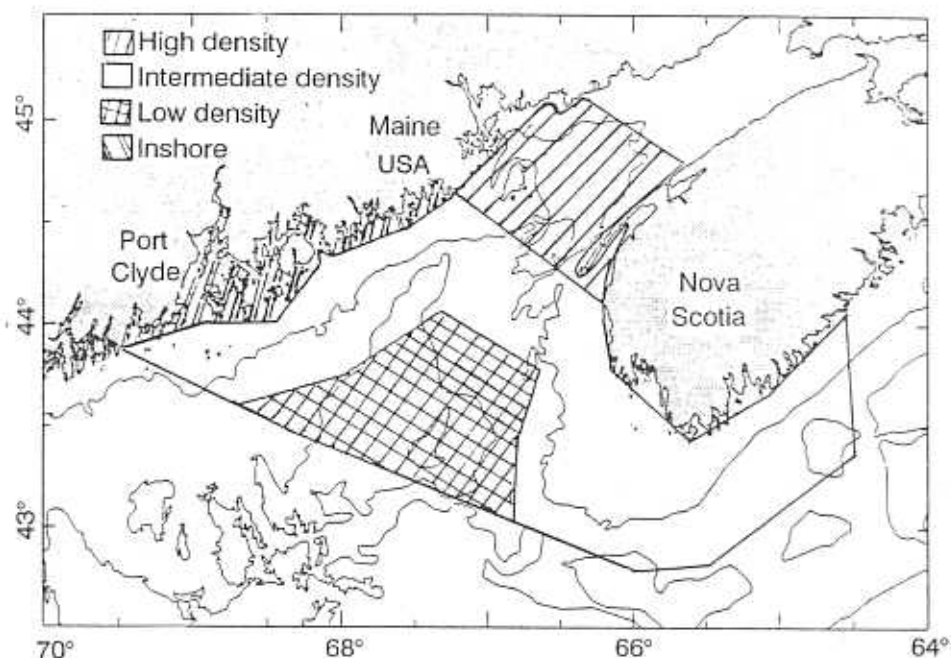

Fig. 1. Study area located in the Gulf of Maine, lower Bay of Fundy and part of the Nova Scotian shelf. Study area divided into four strata: high density; intermediate density; low density; and inshore. Dotted lines represent the 50 and 100 fathom depth contour lines.

Sneak Attack survey

Line transect survey methods were performed in Beaufort sea state two or less along 7 nautical mile (n.mile) transects within four geographical blocks: (A) Penobscot Bay; (B) Jericho and Blue Hill Bays; (C) Frenchman Bay; and (D) Pleasant, Englishman and Machias Bays (Fig. 2). The blocks were assigned on the basis of possible habitat divisions and to facilitate allocation of survey lines. Each block was divided into an inshore and offshore area. The inshore area corresponded to the inshore stratum, defined above, and was delimited as the waters inshore of lines connecting major headlands. The offshore area encompassed waters out to 5 n.miles offshore these lines.

Trackline mileage was allocated in proportion to the surface area of navigable waters. Survey tracklines were divided into 7 n.mile transects (Fig. 3). The sighting team consisted of three observers, a recorder and a helmsman. People rotated among positions every 30 minutes, which was approximately the length of one transect. The ship traveled at 14 knots.

For every detected marine mammal, the data recorded were the position (using LORAN C), species, group size (best, high and low estimate), sighting cue, number of calves, identity of the observer responsible for the sighting, radial distance (estimated visually) and bearing to the initial sighting position (facilitated by the placement of markers of measured radial degrees around the observation area). In addition, at the beginning of each transect and at all marine mammal sightings, vessel speed, water depth, surface water temperature, sea state, swell, weather and glare conditions were recorded (Read and Kraus, 1991).
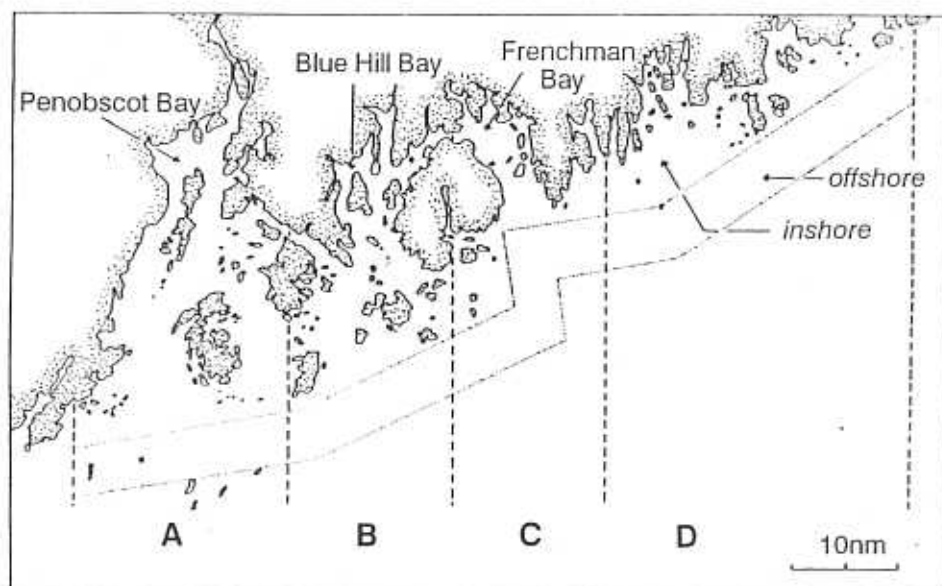

Fig. 2. Area surveyed by the *M/V Sneak Attack* which is divided into four geographical blocks (A, B, C, D). Each block is divided into an inshore area, corresponding to the inshore stratum shown in Fig. 1 and an offshore area 5 n.miles off the inshore area.

Abel-J survey

Trackline mileage in the high density and intermediate density strata was approximately proportional to the stratum area. The trackline length in the low density stratum was less than proportional to the area. The trackline mileage allocation was accomplished by dividing each stratum into 'boxes', each approximately 600 n.miles². Within each box, 90–100 n.miles were surveyed, roughly one day's effort. The order in which the boxes were surveyed was chosen randomly with the constraint that the box to be surveyed on the next day could be reached by traveling during the night. The tracklines within a box followed a zig-zag pattern running along hypothesized density gradients (i.e. perpendicular to density contour lines). Because both a northeastern-southwestern (Kraus *et al.*, 1983b) and an
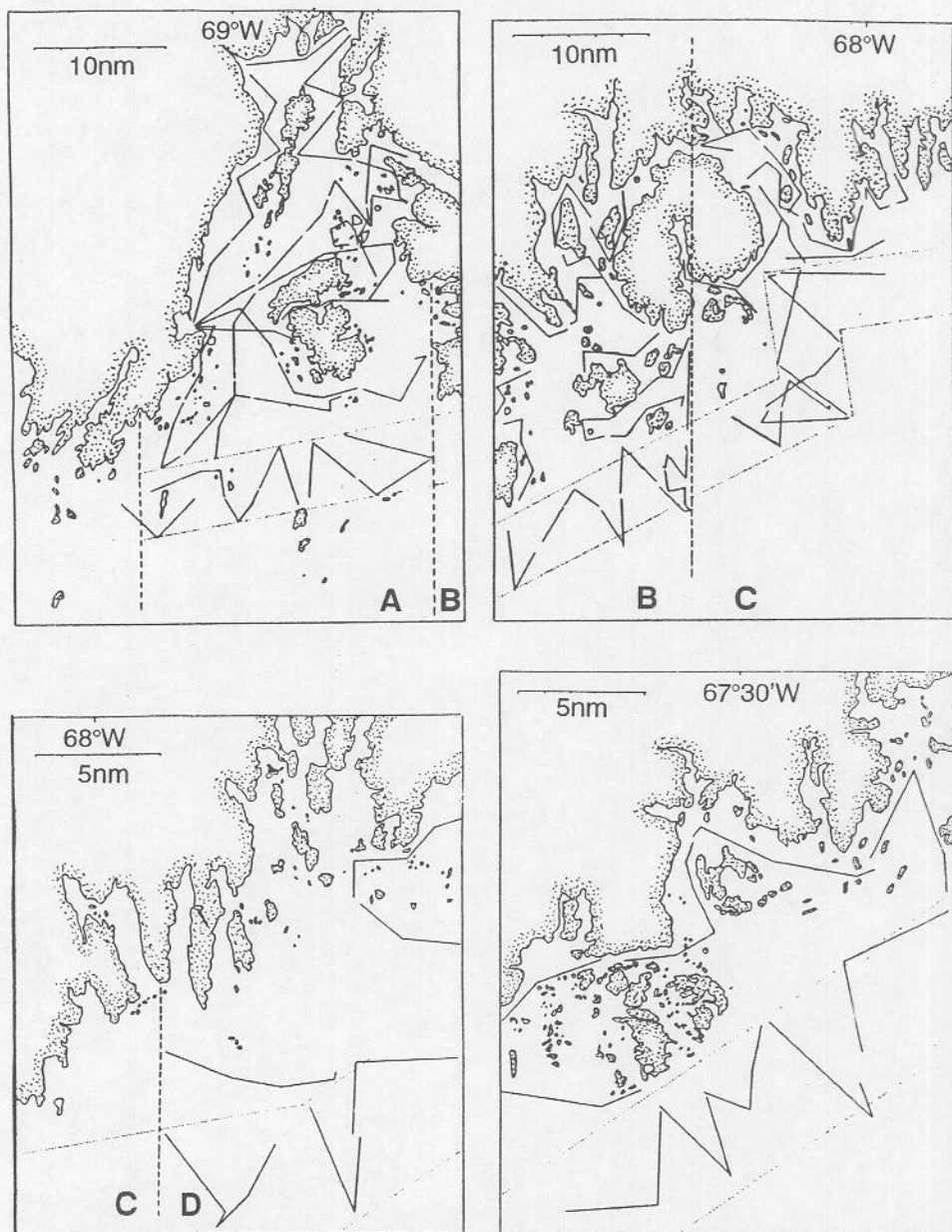
Fig. 3. Tracklines surveyed by the *M/V Sneak Attack* in the four geographical blocks.

inshore-offshore gradient (Gaskin, 1977) had been proposed, some day's tracklines ran north-south (parallel to the shoreline) while other day's ran inshore-offshore (perpendicular to the shoreline) (Fig. 4). The starting point within a box was chosen randomly, again with the constraint that the starting point could be reached by travel during the night.

The tracklines were divided into 'transects' and 'legs' to facilitate estimating a bootstrap confidence interval of the abundance estimate, as has been done in other marine mammal sighting surveys (Øien, 1990; Gerrodette and Wade, 1991). There were 4–8 'transects' per day, where a transect was defined as the time during which the ship's heading and speed was constant. A transect was made up of a consecutive series of 'legs', where a leg was defined as the time during which all conditions were constant. Conditions considered were environmental factors and position of observers, in addition to ship's speed and heading .

The independent observer sighting procedure (Butterworth and Borchers, 1988) was used throughout the survey to allow estimation of abundance corrected for $g(0)$. Two physically separated teams of observers searched simultaneously for marine mammals using the unaided eye. One team was located on the 'upper' crow's nest, 14m above the sea surface, while the other team was located vertically below the upper team on the 'lower' crow's nest, 9m above the sea surface. The two teams could not see or hear each other.

There were four observers per team. Observers did not rotate between teams. Each team surveyed from only one sighting platform. On each observation platform there were three observing positions: port, center and starboard. Observers rotated among positions every 30 minutes, moving from the port to center to starboard observation position and then to a rest position which was not located on the observation platform. Every morning the starting position of the team members was chosen randomly with the constraints that the person in the first rest position rotated systematically and that the time spent in each observation position during the entire survey was approximately the same. Surveys were conducted when the Beaufort sea state was less than or equal to four and the visibility was greater than 500m.

To facilitate determining which groups of animals were detected by both teams, the observers tracked detected harbor porpoise groups, when possible, recording the position of two or three surfacings. The data collected for each marine mammal sighting included: time of sighting (recorded to the nearest second), species, radial distance between the ship and animal group (estimated visually), bearing angle between the ship's line of travel and the line of sight to the animal (measured with a polarus mounted in front of each observation position), group size (best, high and low estimates), direction the group was travelling initially (measured with the polarus), number of mother-calf pairs and sighting cue. The high (low) estimate of group size was defined as the largest (smallest) number of animals that was thought to be in the group. Best group size was defined to be the observer's judgement of most likely estimate of group size.

Data collected by the chief scientist at the beginning of each leg and the end of the day were: position (using LORAN C), ship's speed and bearing, position of each observer and environmental conditions including: wind speed and direction, swell direction and height, Beaufort sea state, presence of rain or fog, percentage of cloud cover, vertical and horizontal position of the sun and glare conditions for each observer as perceived by that observer. The latitude and longitude of each marine mammal sighting was estimated, after the survey, by dead reckoning between the positions recorded for the beginning and end of the leg in which the sightings was made in.

To obtain accurate visual estimates of radial distance between the ship and animal group, the observers were trained and tested. This was accomplished by having observers estimate the distance to a floating wooden replica of a harbor porpoise which was placed at various distances and bearings around the main ship. During the times the replica was being moved using a small boat, the observers, who were standing on their respective observation platform, were instructed not to look at the water. After the replica was placed in the water, the actual distance between the ship and replica was measured from the main ship to the small boat using the ship's radar. Then the small boat moved away

from the floating replica and the observers were instructed to find the replica, visually estimate the distance between the ship and replica and then use the polarus to measure the bearing. During training, the actual distance was immediately reported to the observers. During testing, actual distances were withheld until the end of the test. Training and testing occurred for one day before the survey and then during the survey for a few hours each week.

Analytical procedures

Two analytical techniques were used to estimate the abundance within each stratum and within the entire study area. Both techniques allow the estimation of $g(0)$. The first technique estimates $g(0)$ by the product integral method (Butterworth and Borchers, 1988) which assumes the sighting processes of the two teams are independent and consequentially the distribution of sightings detected by both teams (referred to as duplicate sightings) is predicted, not directly estimated. This assumption has often been necessary because of a small sample size of duplicate sightings. However, the sample size of duplicate sightings from this survey was large enough to permit the use of another technique that estimates abundance which is corrected for $g(0)$.

Using the first technique (product integral method), the abundance of animals ($\hat{N}$) was estimated by:

$$\hat{N} = \sum_{i=1}^{4} \hat{N}_i = \sum_{i=1}^{4} \hat{D}_i \cdot A_i = \sum_{i=1}^{4} \frac{n_i \cdot \hat{f}_i(0)}{2 \cdot L_i \cdot \hat{g}_i(0)} \cdot \hat{E}(s_i) \cdot A_i \tag{1}$$

where

N_i = estimated abundance of animals, corrected for $g(0)$, within stratum i;
$\hat{D}_i$ = estimated density of animals, corrected for $g(0)$, within stratum i;
n_i = number of unique sightings detected within stratum i;
 = $n_{iup} + n_{ilo} - n_{idup}$;
n_{iup} = number of sightings detected by the upper team within stratum i;
n_{ilo} = number of sightings detected by the lower team within stratum i;
n_{idup} = number of sightings detected by both teams within stratum i;
$\hat{f}_i(0)$ = probability density of observed perpendicular distances from stratum i where the distance equals zero
L_i = length of trackline surveyed within stratum i;
$\hat{E}(s_i)$ = average size of porpoise groups detected within stratum i;
A_i = area of stratum i;
i = stratum index, $i=1$ to 4;
$\hat{g}_i(0)$ = probability of detecting an animal on the trackline within stratum i;
 = $\hat{g}_{iup}(0) + \hat{g}_{ilo}(0) - [\hat{g}_{iup}(0) \cdot \hat{g}_{ilo}(0)]$, where

$$\hat{g}_{iup}(0) = \frac{n_{idup}}{n_{ilo}} \cdot \frac{\int_{y=0}^{w} \hat{g}_{ilo}(y)\, dy}{\int_{y=0}^{w} \hat{g}_{iuplo}(y)\, dy} \quad \text{and} \quad \hat{g}_{ilo}(0) = \frac{n_{idup}}{n_{iup}} \cdot \frac{\int_{y=0}^{w} \hat{g}_{iup}(y)\, dy}{\int_{y=0}^{w} \hat{g}_{iuplo}(y)\, dy} \tag{2}$$

and

$\hat{g}_{iup}(y)$ = probability of the upper team detecting a group at perpendicular distance y within stratum i;
$\hat{g}_{ilo}(y)$ = probability of the lower team detecting a group at perpendicular distance y within stratum i;

$\hat{g}_{iuplo}(y)$ = probability of both teams detecting a group at perpendicular distance y within stratum i;

w = maximum perpendicular distance.

Assuming the sighting processes of the two teams were independent, $\hat{g}_{iuplo}(y)$ was estimated by

$$\int_{y=0}^{w} \hat{g}_{iuplo}(y)\ dy = \int_{y=0}^{w} [\hat{g}_{iup}(y) \cdot \hat{g}_{ilo}(y)]dy \tag{3}$$

The value of $f_i(0)$ was estimated using the perpendicular distances of the unique sightings (n_i), where the perpendicular distance recorded by the first team that detected a duplicate sighting was used, regardless of which team made the detection.

The second technique used to estimate abundance, referred here to as the direct duplicate method, differs from the product integral method in that the independence assumption (equation 3) was not made. The animal density corrected for $g(0)$, within a stratum, ($\hat{D}_i$) was estimated directly from the Petersen two-sample mark-recapture equation. Thus, the abundance of animals, $\hat{N}$, was estimated by:

$$\hat{N} = \sum_{i=1}^{4} \hat{N}_i = \sum_{i=1}^{4} \hat{D}_i \cdot A_i = \sum_{i=1}^{4} \frac{\hat{D}_{iup} \cdot \hat{D}_{ilo}}{\hat{D}_{idup}} \cdot A_i \tag{4}$$

where

$\hat{D}_{iup}$ = density of animals as seen by the upper team, not corrected for $g(0)$;
$\hat{D}_{ilo}$ = density of animals as seen by the lower team, not corrected for $g(0)$;
$\hat{D}_{idup}$ = density of animals detected by both teams, not corrected for $g(0)$.

$\hat{D}_{iup}$, was estimated by

$$\hat{D}_{iup} = \frac{n_{iup} \cdot \hat{f}_{iup}(0) \cdot \hat{E}(s_{iup})}{2L_{iup}} \tag{5}$$

$\hat{D}_{ilo}$ and $\hat{D}_{idup}$ were estimated similarly. For comparison purposes, the value of $\hat{g}_i(0)$, under the direct duplicate method, was estimated using equation (2) and assuming $\hat{g}_{iuplo}(y)$ (equation 3) was estimated from the observed perpendicular distances of the duplicate sightings.

Both the product integral and direct duplicate technique requires $\hat{E}(s_i)$, the estimated average group size. The observer's best estimates of group size were used. Several methods were used to determine if the probability of detecting a group of animals changed as a function of group size, referred to as size bias (Quinn, 1985; Drummer and McDonald, 1987). For the data collected within each stratum, a plot of group size versus perpendicular distance was inspected. If there was a significant slope, then size bias may exist. In addition, a covariate analysis was performed using the data from each stratum with the software package SIZTRAN (Drummer, 1991). In such an analysis, the probability of detecting a group ($g(y,s)$) is a bivariate function of both observed perpendicular distance, y, and group size, s, (Drummer and McDonald, 1987; Ramsey et al., 1987). A bivariate detection function is described by the usual models (negative exponential, half normal, etc.) with an additional estimable parameter, α, which is defined as the effect of group size on the detection function. When $\alpha=0$ no effect exists and there is no size bias. In a covariate analysis, the null hypothesis $\alpha=0$ is tested using standard likelihood ratio tests. If the test is rejected, then size bias exists.

For both the product integral and direct duplicate technique, the hazard rate model was fit to unsmeared perpendicular distances, unless another model fit the data better, as was determined by the AIC score (Akaike Information Criteria; Akaike, 1974; Burnham et al., 1987) and visual inspection of the fit near the origin, the most critical region

(Burnham *et al.*, 1980). The computer package DISTANCE (Laake *et al.*, 1991) was used to estimate $g(y)$, where the maximum perpendicular distance (w) was 400m. Using 400m, 8 and 9% of the sightings were deleted from the upper and lower team's data, respectively.

Equations (1) and (4) may represent an over-parameterised model. That is, some parameters within the equations may not differ between strata and, therefore, should not be estimated separately (Burnham *et al.*, 1987; Buckland and Turnock, 1992). To create a reduced, more parsimonious model, each parameter was investigated to determine if the values of the parameter from the high density, intermediate density and inshore stratum differ. The low density stratum had only three sightings and was, therefore, excluded from this test. Differences in $E(s_i)$ and n_i/L_i were investigated using Tukey's studentized range (HSD) multiple comparison test within an ANOVA framework (SAS Institute Inc., 1985). The Kolmogorov-Smirnov statistic (Zar, 1984) was used to determine if there were differences in the shape of the $\hat{g}(y)$ curves.

The estimate of $g(0)$, and consequentially the abundance, was dependent on which sightings were determined to be duplicates. Two people (D. Palka and D. Potter) independently categorized each sighting as a duplicate or non-duplicate sighting by examining the time the sighting was made, the location of the group in relationship to the ship, the direction of travel and the best, high and low estimate of group size. Duplicate sightings were rated as 'definite' or 'possible', depending on the confidence of the judgement.

Equations (1)-(5) were used to estimate abundance of porpoises within the high density and intermediate density strata. Because only three harbor porpoise groups were detected in the low density stratum, all by the lower team, the above equations had to be modified. The abundance estimate for the low density stratum was calculated assuming the detection function, $\hat{g}(0)$ and the average group size was the same in the low density as in the intermediate density stratum, while the values of n_i, L_i and A_i were those associated with the low density stratum.

The abundance within the inshore stratum used data collected aboard both the *R/V Abel-J* and *M/V Sneak Attack*. For this stratum, abundance was estimated by the product of three factors: (1) the $\hat{g}(0)$ corrected density of porpoises within the 5 n.mile strip of offshore waters, as determined by the *R/V Abel-J* survey, (2) the area of the shallow inshore stratum and (3) the ratio of the sighting rate of porpoise groups in inshore waters to the sighting rate in the 5 n.mile strip of offshore waters, as determined by the *M/V Sneak Attack* survey.

The variability of an abundance estimate for a stratum or for the whole study area is represented by the coefficient of variation (CV) and 95% confidence interval (CI). The variability is due to two components: (1) the usual sampling variability of parameters found in equations (1)-(5), given the number of duplicate sightings; and (2) the estimated number of duplicates which involves the uncertainties of categorizing a sighting as a duplicate or non-duplicate sighting (referred to as duplicate determination variability).

The sampling variability was estimated by using bootstrap re-sampling techniques (Efron, 1982). A bootstrap sample was generated by randomly selecting data, with replacement, from the original data. The re-sampling unit was a 'transect' of survey effort within a stratum (4–8 transects per day; 13–78 per stratum). Within a bootstrap sample, the number of transects in a stratum was constrained so that the total length of trackline within a stratum equals the trackline length in the actual survey. If after choosing a random transect, the trackline length exceeded the actual track length then only the first portion of the transect needed to reach the desired track length was used in that bootstrap sample. Because there were only three groups of porpoises detected in the low density stratum, the abundance of animals in the low density stratum within a bootstrap sample

was estimated as described above, except that n_{low} always equaled three (the actual number of groups observed in the low density stratum). The re-sampling procedure was repeated 1,000 times. Thus for each technique, 1,000 values for each stratum of all estimable parameters in equations (1) – (5) were created.

Assuming the two judges were a random sample from the set of possible competent judges, the duplicate determination variability was expressed by two sets of 1,000 bootstrap samples for each technique. One set was created assuming the duplicate sightings were those that were defined by Judge A and the other set assumed the duplicates were those defined by Judge B.

To obtain an estimate of both the sampling and duplicate determination variability of a parameter, the bootstrap distribution for that parameter using one judge's data was pooled with the respective bootstrap distribution from the other judge, resulting in a 'joint' distribution which contains 2,000 estimates of the parameter (Schweder et al., 1991). This joint distribution estimates the sampling distribution of the parameter. The point estimate of the parameter was defined as the median of the corresponding joint bootstrap distribution. The endpoints of the 95% confidence interval of the parameter was estimated by the 2.5 and 97.5 percentile of the corresponding joint bootstrap distribution. The parameters in which this procedure was applied to was $g_i(0)$, $g_{iup}(0)$, $g_{ilo}(0)$, $g_{idup}(0)$, D_i and N_i. The point estimate of N was defined as the summation of the point estimates of N_i.

The CV of the total abundance [$CV(\hat{N})$] was calculated using

$$CV^2(\hat{N}) = \text{vâr}(\hat{D}_T) / \hat{D}_T^2 \qquad (6)$$

where

$$\text{vâr}(\hat{D}_T) = \sum_{i=1}^{4} \left(\frac{A_i}{A} \cdot SE(\hat{D}_i) \right)^2$$

$$\hat{D}_T = \sum_{i=1}^{4} \left(\frac{A_i}{A} \cdot \hat{D}_i \right)$$

and
$\hat{D}_T$ = weighted total density of individuals within all strata;
A = area within all strata.

The $SE(\hat{D}_i)$ was estimated by the standard deviation (SD) of the 2,000 bootstrap estimates within the joint distribution of density of individuals from stratum i.

The percent coefficient of variation of $\hat{N}_i$ ($\%CV(\hat{N}_i)$) was estimated by:

$$\% \, CV \, [\hat{N}_i] = \frac{SE(\hat{N}_i)}{\hat{N}_I} \cdot 100 \qquad (7)$$

where the SE of $\hat{N}_i$ equals the SD of the bootstrap $\hat{N}_i$ estimates within the joint distribution and $\hat{N}_i$ is the point estimate of the joint distribution from stratum i.

RESULTS

Sneak Attack survey

The M/V Sneak Attack travelled 640 n.miles in four geographic areas each of which was divided into the shallow inshore stratum and adjacent offshore five-mile area (Fig. 3). A total of 135 harbor porpoise groups were detected (Table 1). The mean number of sightings per seven mile transect was 1.66 and the mean best estimate of group size was 1.91. There were no significant differences ($p=0.28$) between the number of porpoise

Table 1

Summary of results from the *M/V Sneak Attack* sighting survey in four geographical areas (A,B,C,D). Each geographical area was divided into an inshore and offshore area. The reported results are track length measured in n.miles, area (n.miles^2), number of detected harbor porpoise groups, number of sightings per number of 7 n.mile transects (sighting rate), number of completed transects and average size of detected groups.

	Area	Track length	Area	No. of groups	Sighting rate (N)	Av. group size
A	Inshore	174	350	49	2.09 (23)	1.67
	Offshore	50	100	11	1.38 (8)	1.82
B	Inshore	86	175	25	2.00 (12)	1.64
	Offshore	42	85	9	1.17 (6)	1.56
C	Inshore	64	125	22	2.44 (9)	2.50
	Offshore	51	100	8	1.14 (7)	2.12
D	Inshore	74	150	1	0.17 (6)	2.00
	Offshore	99	200	10	1.25 (8)	2.70
All	Inshore	398	800	97	1.90 (50)	1.85
	Offshore	242	485	38	1.24 (29)	2.05
Total		640	1285	135	1.66 (79)	1.91

sightings per transect in the inshore (1.90, SD=2.23, N=50) and offshore (1.24, SD=1.45, N=29) areas, nor were there significant differences (p=0.89) between the mean group size in the inshore (1.85, SD=1.37, N=97) and offshore (2.05, SD=1.39, N=38) areas (Read and Kraus, 1991). The ratio of the sighting rate of porpoise groups in the inshore stratum to the sighting rate in the offshore five-mile area was 1.53. The value of this ratio was used in the inshore stratum abundance estimate (see below).

Abel-J survey

The *R/V Abel-J* covered approximately 1,961.5 n.miles of trackline in the study area during good weather conditions (Fig. 4; Table 2). In addition, 73.5 n.miles were covered during a bad weather (poor visibility) day; 82.5 n.miles were covered in the inshore bays of Nova Scotia (not in the study area) using both the *R/V Abel-J* and a rigid hulled inflatable 17-foot boat (*Zodiac*[1]); 40.25 n.miles were traveled in Passamaquoddy Bay, Maine (not in the study area) using the *Zodiac*[1]. In total, the trackline length was 2157.8 n.miles.

The data collected during the bad weather day were excluded.

The upper team saw 499 harbor porpoise groups, of which 27 groups were excluded because three had missing data and 24 were made during the bad weather day. This resulted in 472 good sightings detected by the upper team (Fig. 5; Table 2). The lower team saw 391 harbor porpoise groups, of which 16 groups were excluded because they were made on the bad weather day. This resulted in 375 good sightings detected by the lower team (Fig. 5; Table 2). One group of harbor porpoises was detected in the inshore bays of Nova Scotia, another was detected in Passamaquoddy Bay, Maine. These two sightings were not used in the analysis.

The best estimate of $E(s)$ was determined to be the arithmetic mean, $\bar{s}$, because size bias was not significant. This is illustrated by the fact that the slope between group size and

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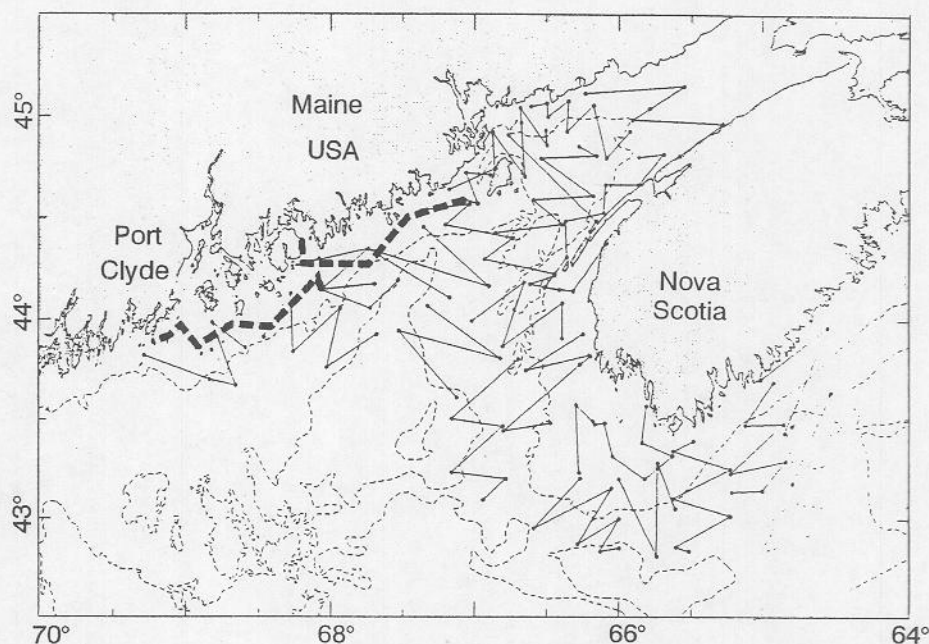[1] Mention of trade names does not constitute endorsement by NMFS.

Fig. 4. Tracklines surveyed by the *R/V Abel-J*. Heavy dashed line are tracklines within the 5 n.mile offshore area. Other tracklines are within the high density, intermediate density and low density stratum.

Table 2

Summary of results from the *R/V Abel-J* line transect survey in four strata: high density (High), intermediate density (Interm.), low density (Low) and inshore (Inshore). The reported results are length of trackline in n.miles (% of total length in parentheses), area of stratum in n.miles^2 (% of total area in parentheses), total number of groups detected by the upper and lower teams, (number of groups within a perpendicular distance of 400m from the trackline in parentheses), average size of groups within 400m (%CV in parentheses).

Strata	Track length (%)	Area (%)	Number of groups		Av. (%CV) of group size	
			Upper	Lower	Upper	Lower
High	310 (0.16)	1,552 (0.11)	236 (217)	203 (184)	2.97 (3.9)	2.99 (7.3)
Interm.	1,333 (0.68)	9,038 (0.65)	216 (197)	149 (144)	2.76 (4.2)	2.38 (5.5)
Low	189 (0.10)	2,674 (0.19)	0 (0)	3 (3)	0	2.00 (0.5)
Inshore	130 (0.07)	637 (0.05)	20 (19)	20 (17)	4.26 (15.5)	3.29 (14.9)
Total	1,962 (1)	13,901 (1)	472 (433)	375 (345)	2.93 (2.9)	2.75 (4.8)

perpendicular distance, as recorded by the upper team was not significant, (H_0: slope=0 for all strata together, $p=0.36$). However, the lower team's estimates of group size decreased slightly as perpendicular distance increased (H_0: slope=0 for all strata together, $p=0.04$). The effect of group size (α in a bivariate model) was not significant for every combination of team and stratum, given the negative exponential, half normal and general exponential model, i.e., there was no obvious group size bias (Table 3).
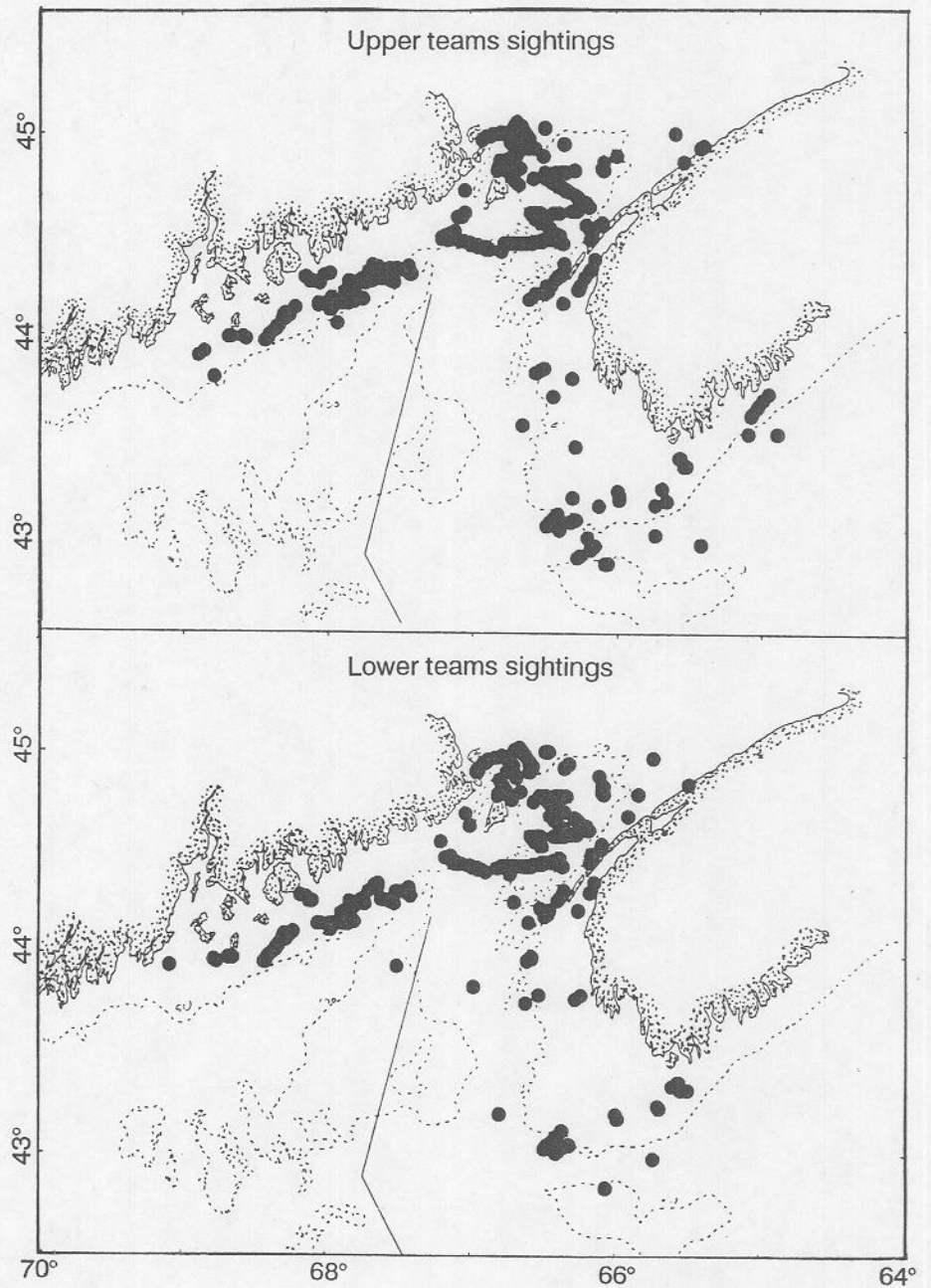
Fig. 5. Location of harbor porpoise groups that were detected by the upper and lower team aboard the *R/V Abel-J*. Solid line through center of area represents the US – Canadian border.

Table 3

The bivariate models that were investigated are negative exponential, half normal and general exponential. Results from each model include the value of α, which reflects the effect of group size ($\alpha=0$ indicates no group size effect), p-value from the test $H_0:\alpha=0$ vs $H_1:\alpha\neq0$, Akaike information criteria (AIC) and estimated density of schools. * indicates the least AIC value, which represents the best model that fits the data. ◄ indicates the model (bivariate or univariate) that resulted in the greater school density estimate.

Model	Model	α	p-value	AIC	School density
Upper team - high density stratum					
Negative exponential	bivariate	-0.024	0.274	-599.72	3.723◄
	univariate	-	-	-601.70*	3.707
Half normal	bivariate	-0.041	0.310	-617.54	2.345◄
	univariate	-	-	-619.45*	2.344
General exponential	bivariate	-0.008	0.261	-617.20	2.615
	univariate	-	-	-618.75*	2.643◄
Upper team - intermediate density stratum					
Negative exponential	bivariate	-0.369	0.496	-568.17*	0.839◄
	univariate	-	-	-564.22	0.813
Half normal	bivariate	-0.353	0.500	-588.74*	0.533◄
	univariate	-	-	-580.07	0.514
General exponential	bivariate	-0.380	0.500	-587.45*	0.580◄
	univariate	-	-	-578.84	0.579
Upper team - inshore stratum					
Negative exponential	bivariate	-0.189	0.321	-60.18	1.041◄
	univariate	-	-	-62.03*	0.984
Half normal	bivariate	-0.150	0.315	-60.76	0.640◄
	univariate	-	-	-62.65*	0.613
General exponential	bivariate	-0.216	0.333	-59.13	0.760
	univariate	-	-	-61.00*	0.780◄
Lower team - high density stratum					
Negative exponential	bivariate	-0.041	0.207	-515.11	3.201◄
	univariate	-	-	-517.06*	3.185
Half normal	bivariate	-0.048	0.243	-545.47	2.092◄
	univariate	-	-	-547.47*	2.092
General exponential	bivariate	-0.060	0.164	-545.81	2.142◄
	univariate	-	-	-548.43*	2.124
Lower team - intermediate density stratum					
Negative exponential	bivariate	-0.283	0.474	-434.22*	0.667◄
	univariate	-	-	-433.54	0.651
Half normal	bivariate	-0.319	0.497	-447.97*	0.425◄
	univariate	-	-	-443.22	0.411
General exponential	bivariate	-0.318	0.495	-446.62*	0.470
	univariate	-	-	-441.31	0.474◄
Lower team - inshore stratum					
Negative exponential	bivariate	+0.148	0.204	-51.60	0.839◄
	univariate	-	-	-53.50*	0.795
Half normal	bivariate	+0.358	0.109	-52.68	0.527◄
	univariate	-	-	-54.09*	0.495
General exponential	bivariate	+0.301	0.142	-50.74	0.604
	univariate	-	-	-52.34*	0.628◄

To determine the best reduced, stratified model [equations (1) and (4)], the estimates of group size and encounter rate, along with the shape of the estimated detection functions were compared between strata. The average group size (± 1SD) as estimated by the upper and lower team was 2.93 ±1.75 and 2.75 ±2.46, respectively (Table 2). Mean group sizes did not differ significantly between teams (HSD critical value=2.78; SAS Institute Inc., 1985). Mean group size from the intermediate density stratum (upper: 2.76; lower:2.38)
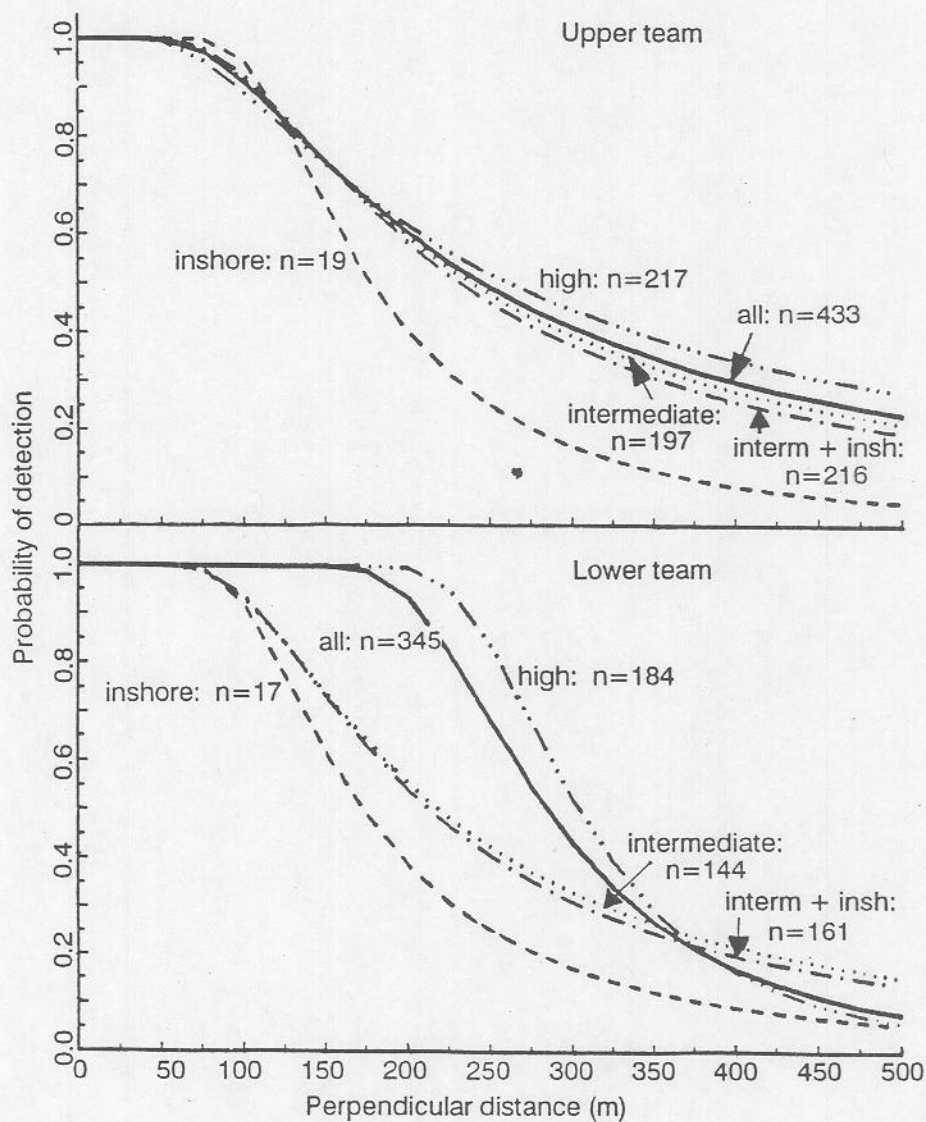

Fig. 6. Detection functions estimated from data collected within the high density, intermediate density and inshore strata by the upper and lower team members (high, intermediate and inshore). In addition, the detection function estimated from data pooled over all strata is displayed (all).

was statistically different than that from either the high density (upper:2.97; lower:2.99) or inshore stratum (upper:4.26; lower:3.29) (HSD critical value 3.32). The encounter rate (n_i/L_i) from the high density stratum (upper:0.76 groups per n.miles; lower:0.66) was statistically different than either the inshore (upper:0.15; lower:0.15) or intermediate density stratum (upper:0.16; lower:0.11) (HSD critical value=3.337). Within a team, there were no significant differences between estimated detection functions for any of the strata (Fig. 6; for all pairwise comparisons within a team the Kolmogorov-Smirnov D value was greater than the critical value for that pair). Thus, the preferred reduced stratified model is where $f(0)$ is estimated from data pooled over strata and the other parameters are estimated by strata.

The number of 'definite' duplicate sightings as determined by Judge A and B was 113 and 138, respectively, while the number of 'possible' duplicates were 54 and 8, respectively (Table 4). The sum of definite and possible duplicate sightings as determined by Judge A and B was 167 and 146, respectively. Using the weighing scheme suggested in Butterworth and Borchers (1988) i.e. sum the number of definite duplicates and 2/3 of the possible duplicates, the resulting numbers of duplicates were 149 (Judge A) and 143 (Judge B). Of the number of harbor porpoise groups detected by the upper team, 35% and 31% of the groups were categorized as either a definite or possible duplicate sighting by Judge A and B, respectively (Table 5).

Table 4

Number of duplicate sightings within three strata (high density, intermediate density and inshore) as determined by two judges (A=Palka, B=Potter). The duplicates were categorized as definitely a duplicate (Definite) or possibly a duplicate (Possible). Definite + Possible is sum of definite and possible duplicates. A weighted number of duplicates is the sum of definite duplicates and 2/3 of the possible duplicates (Definite + 2/3 Possible).

Stratum	Definite A	Definite B	Possible A	Possible B	Definite + Possible A	Definite + Possible B	Definite + 2/3 Possible A	Definite + 2/3 Possible B
High	60	71	30	6	90	77	80	75
Intermediate	46	60	22	2	68	62	61	61
Inshore	7	7	2	0	9	7	8	7
Total	113	138	54	8	167	146	149	143

Table 5

Ratio of number of duplicate sightings to number of sightings detected by the upper team. Definition of headings in Table 4.

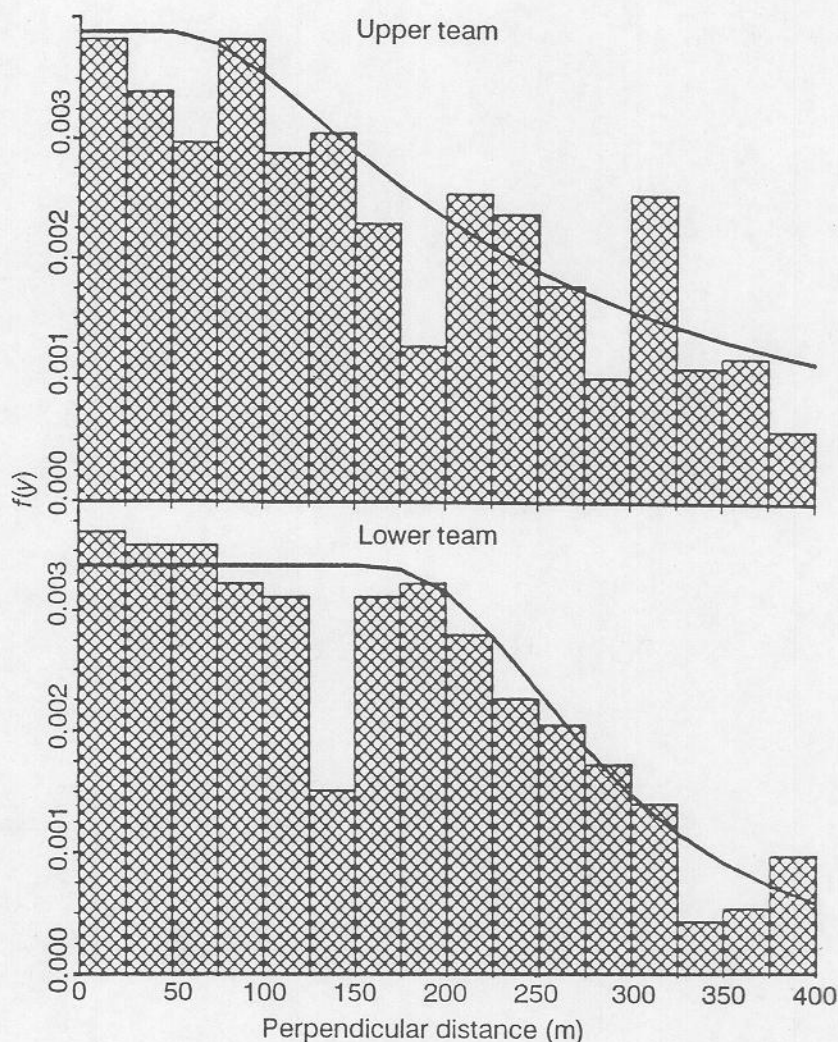| Stratum	Definite A	Definite B	Possible A	Possible B	Definite + Possible A	Definite + Possible B	Definite + 2/3 Possible A	Definite + 2/3 Possible B
High	0.25	0.30	0.13	0.02	0.38	0.33	0.33	0.32
Intermediate	0.21	0.28	0.10	0.01	0.31	0.29	0.28	0.28
Inshore	0.35	0.35	0.10	0.00	0.45	0.35	0.40	0.35
Total	0.24	0.29	0.11	0.02	0.35	0.31	0.32	0.30

Fig. 7. A histogram of perpendicular distances from all strata that were detected by the upper and lower team is overlaid by the estimated hazard rate detection function.

The strategy of categorizing a duplicate differed between the two judges. Judge A had more stringent criteria for a definite duplicate and looser criteria for a possible duplicate. Of the 138 sightings categorized as a definite duplicate by Judge B, 92 (67%) were categorized as a definite duplicate by Judge A and 122 (88%) were categorized as either a definite or possible duplicate by Judge A (Table 6). However, of the 54 possible duplicates as categorized by Judge A, 20 (37%) were categorized as a non-duplicate sighting by Judge B (Table 6). After both judges reviewed these sightings, it was agreed upon that the criteria used by Judge A to assign a sighting as a possible duplicate was too loose. Therefore, for the rest of this analysis, only the definite duplicate sightings will be used.
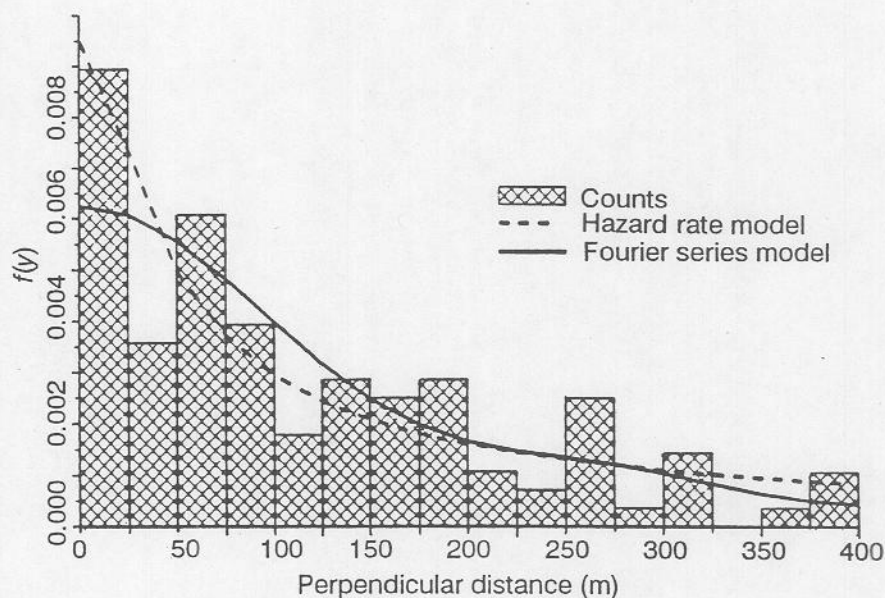
Fig. 8. Comparison of the estimated hazard rate and third order Fourier detection function overlaying a histogram of the observed perpendicular distances of the duplicate sightings as defined by Judge A.

The hazard rate model fitted the perpendicular distance data well (Fig. 7), with the exception of the distance data from the duplicate sightings as assigned by Judge A (Fig. 8). Because of a peak in the perpendicular distances at the origin (near the trackline), a third order Fourier model fit better than did the hazard rate model (Fig. 8), as was noted in Buckland (1985). Therefore, in the bootstrap iterations used to estimate variance, a third order Fourier model was used to fit only the bootstrap duplicate data from Judge A; the hazard rate model was used elsewhere.

The estimated effective half strip width (ESW) for the upper and lower teams was 258m (SE=16.4) and 296m (SE=44.1), respectively (Table 7). This difference is not significant ($z=0.81$; $p=0.42$). No significant difference was found between the ESW estimated from

Table 6

Comparison of duplicate classification of each individual sighting that was declared a Definite or Possible duplicate sighting by either of the two judges. If a sighting was declared as a duplicate by a judge but not by the other then that sighting was classified as a non-duplicate according to the latter judge.

		Judge A			
		Definite	Possible	Non-duplicate	Total
	Definite	92	30	16	138
Judge B	Possible	3	4	1	8
	Non-duplicate	18	20	x	39
	Total	113	54	17	185

Table 7

Effective strip half-width (ESW) in meters and its standard error as estimated from data pooled over strata for each team (Upper only and Lower only), for the duplicate sightings as predicted by the product integral method (Upper - Lower) and for duplicate sightings as estimated from the duplicates which were determined by either judge.

Data source	ESW	SE(ESW)	Data source	ESW	SE(ESW)
Upper only	257.7	16.4	Dups only - Judge A	160.3	20.2
Lower only	295.8	44.1	Dups only - Judge B	204.9	24.0
Upper - Lower	260.6	25.8			

the duplicate sightings as determined by Judge A (160m; SE=20.2) and those determined by Judge B (205m; SE=24.0) ($z=1.42$; $p=0.16$). The ESW of the duplicate sightings as predicted by the product integral method ($\hat{g}_{up}(y)\cdot\hat{g}_{lo}(y)$) was 261m (SE=25.8) (Table 7).

The point estimates of $g(0)$ for the upper team within the various strata were higher than the corresponding $g(0)$ from the lower team's data (upper: 0.46 to 0.62; lower: 0.33 to 0.52; Table 8), though the differences were not significant (pairwise z-tests). The point estimate of $g_i(0)$ as estimated by the direct duplicate method (range: 0.71–0.82) was slightly higher than that estimated by the product integral method (range: 0.65–0.75) (Table 9), though the difference between the differences are not significant. An area weighted average of $g(0)$ estimated by the product integral and direct duplicate method was 0.66 (SE=0.07)

Table 8

Estimates of $g_{i_{up}}(0)$ and $g_{i_{lo}}(0)$ as determined by the product integral method and direct duplicate method, where i is the high density, intermediate density, low density and inshore stratum.

Stratum	Team	Product integral		Direct duplicate		Stratum	Team	Product integral		Direct duplicate	
		$g(0)$	SE(g)	$g(0)$	SE(g)			$g(0)$	SE(g)	$g(0)$	SE(g)
High	Upper	0.46	0.06	0.53	0.10	Low	Upper	0.46	0.09	0.53	0.11
	Lower	0.37	0.09	0.43	0.06		Lower	0.33	0.10	0.38	0.07
Interm.	Upper	0.46	0.09	0.53	0.11	Inshore	Upper	0.53	0.13	0.62	0.18
	Lower	0.33	0.10	0.38	0.07		Lower	0.45	0.18	0.52	0.17

Table 9

Estimates of $g_i(0)$ as determined by the product integral method (PI) and direct duplicate method (DD), where i is the high density, intermediate density, low density and inshore stratum. In addition, the area weighted average $g(0)$ is presented.

Stratum	Method	$g(0)$	SE($g(0)$)	Strata	Method	$g(0)$	SE($g(0)$)
High	PI	0.66	0.07	Inshore	PI	0.75	0.14
	DD	0.73	0.07		DD	0.82	0.15
Intermediate	PI	0.65	0.10	Average	PI	0.66	0.07
	DD	0.71	0.09		DD	0.72	0.06
Low	PI	0.65	0.10				
	DD	0.71	0.09				

Table 10

Using either the product integral or direct duplicate method, the following results are presented: estimated density (animals per nmi^2) where $g(0)=1$ (uncorrected density) and its standard error (SE), estimated density including an estimate for $g(0)$ (corrected density) and its standard error and estimated abundance with its standard error and coefficient of variation.

Stratum	Uncorrected density (SE)	Corrected density (SE)	Abundance	SE(N)	CV(N)
Product integral method					
High	10.3 (2.60)	15.6 (3.85)	24,287	5,976	0.25
Intermediate	1.8 (0.50)	2.9 (0.70)	25,820	6,331	0.25
Low	0.15 (0.01)	0.23 (0.04)	616	96	0.16
Inshore	4.2 (1.46)	5.7 (2.36)	3,603	1,506	0.42
Direct duplicate method					
High	3.8 (1.14)	10.9 (5.71)	16,900	8,862	0.52
Intermediate	0.6 (0.22)	1.9 (0.70)	16,944	6,340	0.37
Low	0.15 (0.01)	0.23 (0.04)	616	96	0.16
Inshore	2.0 (1.09)	4.8 (2.29)	3,023	1,459	0.48

and 0.72 (SE=0.06), respectively. This average $\hat{g}(0)$ is the best overall estimate of $g(0)$ for this survey.

The estimated density within the high density stratum was substantially higher than any other stratum (Table 10). The density within the inshore stratum was the next highest, while the density within the low density stratum was the lowest. The product integral technique resulted in higher density estimates than did the direct duplicate method (Table 10), though the differences were not significant (high: $z=0.68$ $p=0.50$; intermediate: $z=1.01$ $p=0.31$; inshore: $z=0.27$ $p=0.28$).

The abundance estimated for the high density and intermediate density strata were similar (Table 10), despite the large difference in strata areas. The product integral abundance point estimates for each stratum was larger than the direct duplicate abundance point estimate for the corresponding stratum, although the differences were insignificant. Total abundance estimates were 37,500 (CV=28.8%) with a 95% CI of (26,600 to 86,400) and 54,300 (CV=16.3%) with a 95% CI of (38,100 to 71,900), as determined from the direct duplicate and product integral techniques, respectively (Table 11). The difference between the total abundance estimates from the two techniques was not significant ($z=1.21$; $p=0.23$).

Table 11

The abundance of each stratum and the entire survey area as estimated by the product integral or direct duplicate method. Also included is the coefficient of variation and upper and lower 95% confidence limits (UCL and LCL) as estimated using bootstrap resampling techniques.

	Abundance (%CV)	LCL	UCL	Abundance (%CV)	LCL	UCL
	Product integral method			**Direct duplicate method**		
High	24,287(0.25)	11,975	34,878	16,900 (0.52)	8,572	45,597
Intermediate	25,820(0.25)	15,082	39,167	16,944 (0.37)	10,702	36,097
Low	616(0.16)	451	804	616 (0.16)	451	804
Inshore	3,603(0.42)	1,308	7,320	3,023 (0.51)	1,239	6,712
Total	54,326(0.16)	38,140	71,930	37,483 (0.29)	26,643	86,369

DISCUSSION

The abundance estimate presented here is larger than previous estimates, largely due to the greater survey area. In addition, most of the previous estimates did not include an estimate of $g(0)$. The estimate of $g(0)$ made from the present dataset (0.72) is similar to that estimated by Barlow (1988) for harbor porpoises (0.78), who also used the two independent team sighting procedure. However, the present estimate of $g(0)$ is larger than the estimate of $g(0)$ for northeastern Atlantic minke whales (0.51; Schweder et al., 1992). Minke whales are also difficult to detect, have no obvious blow and are usually found in small groups. The estimate of $g(0)$ for minke whales was made using the parallel ship sighting procedure and a different analysis procedure.

Of the two techniques to estimate abundance that were presented here, the direct duplicate method is the preferred technique. Both techniques assume the two teams are independent. However, the direct duplicate method uses a weaker version of the assumption. That is, the product integral method predicts the distribution of duplicate sightings to be the product of $g_{up}(y)$ and $g_{lo}(y)$, as estimated separately from data from each platform. The direct duplicate method does not predict the distribution of the duplicate sightings, but directly estimates the distribution from the duplicate sighting's data. As was discussed in Butterworth and Borchers (1988) and Schweder (1990), the independence assumption (equation 3) may not be valid, even on a theoretical basis. Schweder (1990) suggested that this is because some factors may not act independently to the sighting processes of the two teams and therefore, the two teams are conditionally dependent. The two teams in this survey may be conditionally dependent as is evident by the fact that the product integral method predicted more duplicate sightings near the trackline than that observed from the actual duplicate sightings (Fig. 9). This phenomenon was also noted in Butterworth and Borchers (1988). In conclusion, because the direct duplicate method does not explicitly use the independence assumption it is the preferred method. The disadvantage of the direct duplicate method is that a large number of duplicate sightings are required (>40; Burnham et al., 1980) to accurately estimate the $g_{dup}(y)$ distribution.

The estimates presented here have substantial uncertainty, as reflected in the relatively large CV of 28.8%. The largest component of this variation is the encounter rate (n/L; Table 12). By definition, the CV(n/L) should only include sampling variation. However, practically, the CV(n/L) includes both sampling variation and variation in the spatial distribution of the animals. The encounter rate does have spatial structure; i.e. there is evidence of a density gradient related to ocean depth (Fig. 5). Other analysis methods are needed to properly account for this spatial variability, for example, Schweder (1977) and Thompson (1991).

Table 12

Coefficient of variation of various parameters in the density equation. Also, the percentage of the CV of a parameter with respect to the CV of the density when $g(0)$ is assumed to equal one. Estimates are for the high density, intermediate density and inshore stratum, using data from each team.

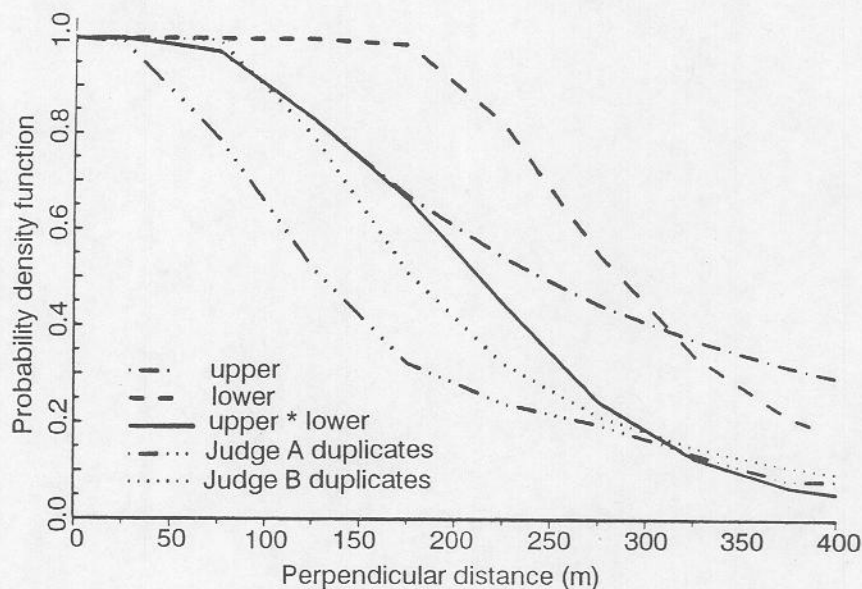| Parameter	CV	%	CV	%	CV	%	Parameter	CV	%	CV	%	CV	%
Upper team							**Lower team**						
n/L	21.4	75.1	21.3	76.9	31.0	52.8	n/L	22.1	86.5	24.0	78.9	26.9	45.8
$f(0)$	11.7	22.4	10.9	20.1	24.8	33.9	$f(0)$	4.8	4.1	11.1	16.9	25.2	40.2
s	3.9	2.5	4.2	3.0	15.5	13.3	s	7.3	9.4	5.5	4.2	14.9	14.0
D	24.7	100	24.3	100	42.6	100	D	23.7	100	27.0	100	39.8	100

Fig. 9. Comparison of the distribution of duplicate sightings as predicted by the product integral method (upper*lower) and as estimated from the observed perpendicular distances of duplicate sightings which were determined by either Judge A or Judge B. For reference, the distribution of perpendicular distances estimated from the data collected by the upper and lower teams are also displayed.

In addition to the spatial structure in the encounter rate, there are several other possible sources of uncertainty unaccounted for in this study. These sources include incomplete coverage of the animals' range, porpoise avoidance of the ship, observer and/or platform heterogeneity and effects of other environmental conditions on sighting rates and $g(0)$. The boundaries of the study area were selected on the basis of previous sighting data. Sighting surveys were performed from a *Zodiac*[1] and the *R/V Abel-J* in coastal southeastern Nova Scotia and Passamaquoddy Bay, Maine, both regions not included in the survey area. During these surveys two porpoise groups were detected in 131 n.miles of searching. This sighting rate is much lower than that observed during the *M/V Sneak Attack* survey, also in coastal waters. Also, one group of harbor porpoises was reported south of the southern boundary along the Maine coast by the survey team on the *M/V Sneak Attack* (Read and Kraus, 1991). Overall, the spatial distribution of the observed sightings suggest that the *a priori* boundaries nearly reflect the actual boundaries.

It has been suggested that harbor porpoises avoid ships (Gaskin, 1977; Kraus *et al.*, 1983b; Polacheck and Thorpe, 1990). If porpoises alter their behavior before being detected by observers on the ship, then the abundance estimate will be biased (Turnock and Quinn, 1991). In the future, the distance at which the porpoises start altering their behavior should be demonstrated to determine if, and to what extent, the abundance estimate is biased.

Buckland (1992) illustrated that heterogeneities have effects on the abundance estimate. During the present survey it is possible there were heterogeneities between the platforms. This means the relative efficiency of the two platforms may have varied with environmental or other factors (Buckland, 1992). This could be illustrated by the fact that

$g_{up}(0)$ was greater than $g_{lo}(0)$, though the difference was not significant (Table 8). The effect of this heterogeneity on the abundance estimate is unknown. An investigation into whether this and other heterogeneities exist may be feasible because some of the necessary data have already been collected during this survey.

Factors other than perpendicular distance may influence the shape of the detection function and consequentially the abundance estimate. Examples of possible influential factors are group size (Drummer and McDonald, 1987) and Beaufort sea state (Gunnlaugsson and Sigurjónsson, 1990). Not including such factors will result in an incorrect abundance estimate. In this study, group size was determined not to be influential (Table 3). Beaufort sea state information was also collected during this survey. Incorporating Beaufort sea state into the bivariate detection functions in SIZTRAN (Drummer, 1991) resulted in the conclusion that Beaufort sea state was not an influential factor, despite the fact that the sighting rate decreased as Beaufort sea state increased. The same conclusion was reached by Gunnlaugsson and Sigurjónsson (1990). Possible explanations for this contradiction are that the line transect technique is robust to the amount of variability that occurs within the range of Beaufort sea state 0 to 3 or possibly the Beaufort sea state scale is not representative of the overall environmental conditions, which actually does influence the detection function.

ACKNOWLEDGEMENTS

REFERENCES

Akaike, H. 1974. A new look at the statistical model identification. IEEE Trans. Autom. Contr. AC-19:716–23.

Anonymous. 1992. Harbour porpoise in eastern North America: status and research needs. Northeast Fisheries Center reference document 92–06, NMFS, Woods Hole, Mass. 28pp.

Barlow, J. 1988. Harbor porpoise, *Phocoena phocoena*, abundance estimation for California, Oregon and Washington: I. Ship surveys. *Fish. Bull., US* 86(3):417–32.

Buckland, S.T. 1985. Perpendicular distance models for line transect sampling. *Biometrics* 41:177–95.

Buckland, S.T. 1992. Effects of heterogeneity on estimation of probability of detection on the trackline. *Rep. int. Whal. Commn* 42:569–73.

Buckland, S.T. and Turnock, B.J. 1992. A robust line transect method. *Biometrics* 48:901–9.

Burnham, K.P., Anderson, D.R. and Laake, J.L. 1980. Estimation of density from line transect sampling of biological populations. *Wildl. Monogr.* 72:1–202.

Burnham, K.P., Anderson, D.R., White, G.C., Brownie, C. and Pollock, K.H. 1987. *American Fisheries Society Monographs.* No. 5. *Design and Analysis Methods for Fish Survival Experiments Based On Release-Recapture.* American Fisheries Society, Bethesda, Maryland. x+437pp.

Butterworth, D.S. and Borchers, D.L. 1988. Estimates of g(0) for minke schools from the results of the independent observer experiment on the 1985/86 and 1986/87 IWC/IDCR Antarctic assessment cruises. *Rep. int. Whal. Commn* 38:301–13.

Drummer, T.D. 1991. SIZTRAN: analysis of size-based line transect data. *Wildl. Soc. Bull.* 19:117–8.

Drummer, T.D. and McDonald, L.L. 1987. Size-bias in line transect sampling. *Biometrics* 43:13–21.

Efron, B. 1982. *Society for Industrial and Applied Mathematics, Monographs.* No. 38. *The Jacknife, the Bootstrap, and Other Resampling Plans.* Arrowsmith Ltd, Bristol, England. 92pp.

Gaskin, D.E. 1977. Harbour porpoise *Phocoena phocoena* (L.) in the western approaches to the Bay of Fundy 1969–75. *Rep. int. Whal. Commn* 27:487–92.

Gaskin, D.E., Read, A.J., Watts, P.F. and Smith, G.J.D. 1985. Population dispersal, size, and interactions of harbour porpoises in the Bay of Fundy and Gulf of Maine. *Can. Tech. Rep. Fish. Aquat. Sci.* 1291:1–28.

Gerrodette, T. and Wade, P. 1991. Monitoring trends in dolphin abundance in the eastern tropical Pacific: Analysis of 1989 data. *Rep. int. Whal. Commn* 41:511–5.

Gunnlaugsson, T. and Sigurjónsson, J. 1990. NASS-87: Estimation of whale abundance based on observations made onboard Icelandic and Faroese survey vessels. *Rep. int. Whal. Commn* 40:571–80.

Kraus, S.D., Gilbert, J.R. and Prescott, J.H. 1983a. A comparison of aerial, shipboard and land-based survey methodology for the harbor porpoise, *Phocoena phocoena*. *Fish. Bull., US* 81(4):910–3.

Kraus, S.D., Prescott, J.H. and Stone, G.S. 1983b. Harbor porpoise, *Phocoena phocoena*, in the US coastal waters of the Gulf of Maine: a survey to determine seasonal distribution and abundance. Final Report to United States Department of Commerce, National Marine Fisheries Services Contract No. NA-82-FA-C-00027, NMFS, Woods Hole, MA 02543. 22pp.

Laake, J.L., Buckland, S.T., Anderson, D.R. and Burnham, K.P. 1991. *DISTANCE User's Guide*. Colorado Cooperative Fish and Wildlife Research Unit, Colorado State University, Fort Collins, CO 80523, USA. 53pp.

Øien, N. 1990. Estimates of $g(0)$ for minke whales based on an independent observer experiment during the Norwegian sightings surveys in July 1988. *Rep. int. Whal. Commn* 40:331–5.

Polacheck, T. 1989. Harbor porpoises and the gilllnet fishery. *Oceanus* 32(1):63–70.

Polacheck, T. 1994a. Double team field tests of line transect methods for shipboard sighting surveys for harbor porpoises. (Published in this volume.)

Polacheck, T. 1994b. The effect of increasing observer trackline effort in shipboard line transect surveys for harbor porpoise. (Published in this volume.)

Polacheck, T. and Smith, T.D. 1989. A proposed methodology for field testing line transect theory for shipboard surveys of cetaceans. *Rep. int. Whal. Commn* 39:341–5.

Polacheck, T. and Smith, T. 1990. Simulation results on the effects of dive time and movements on line transect estimates. Paper SC/42/NHMi31 presented to the IWC Scientific Committee, June 1990 (unpublished). 13pp.

Polacheck, T. and Thorpe, L. 1990. The swimming direction of harbor porpoise in relationship to a survey vessel. *Rep. int. Whal. Commn* 40:463–70.

Polacheck, T., Smith, T.D. and Waring, G.T. 1990. Review of methods for assessing the status of the harbor porpoise population in the Gulf of Maine and Bay of Fundy regions. Results of an at-sea workshop. Northeast Fisheries Science Center Reference Document 90–09, NMFS, Woods Hole, MA 02543. 10pp.

Polacheck, T., Wenzel, F.W. and Early, G. 1994. What do stranding data say about harbour porpoise (*Phocoena phocoena*)? (Published in this volume.)

Prescott, J.H., Kraus, S.D., Fiorelli, P., Gaskin, D.E., Smith, G.J.D. and Brander, M. 1981. Harbor porpoise (*Phocoena phocoena*) distribution, abundance, survey methodology and preliminary notes on habitat use and threats. Final Report to United States Department of Commerce, National Marine Fisheries Service. Contract No. NA81FAC00023, NMFS, Woods Hole, MA 02543.

Quinn, T.J. 1985. Line transect estimators for schooling populations. *Fish. Res. (Amst.)* 3:183–99.

Ramsey, F.L., Wildman, V. and Engbring, J. 1987. Covariate adjustments to effective area in variable-area wildlife surveys. *Biometrics* 43:1–11.

Read, A.J. and Kraus, S.D. 1991. Harbour porpoise distribution and relative density in the waters of coastal Maine. Final Report to United States Department of Commerce, National Marine Fisheries Service Contract No. 40 EANF101538. 23pp.

Read, A.J., Kraus, S.D., Bisack, K.D. and Palka, D. 1993. Harbor porpoises and gill nets in the Gulf of Maine. *Conserv. Biol.* 7(1):189–93.

SAS Institute Inc. 1985. *SAS User's Guide: Statistics*. 5th Edn. SAS Institute Inc. 956pp.

Schweder, T. 1977. Point process models for line transect experiments. pp. 221–42. *In:* R.R. Barra, F. Brodeau, G. Romier and B. Van Cutsem (eds.) *Recent Developments in Statistics*. North Holland.

Schweder, T. 1990. Independent observer experiments to estimate the detection function in line transect surveys of whales. *Rep. int. Whal. Commn* 40:349–55.

Schweder, T., Øien, N. and Høst, G. 1991. Estimates of the detection probability for shipboard surveys of northeastern Atlantic minke whales, based on a parallel ship experiment. *Rep. int. Whal. Commn* 41:417–32.

Schweder, T., Øien, N. and Høst, G. 1992. Estimates of $g(0)$ for northeastern Atlantic minke whales based on independent observer experiments in 1989 and 1990, found by the hazard probability method. *Rep. int. Whal. Commn* 42:399–405.

Smith, T.D., Palka, D. and Bisack, K. 1991. Preliminary estimates of harbor porpoise abundance and by-catch. Northeast Fisheries Science Center. Reference Document 91–04. Northeast Fisheries Science Center, Woods Hole, MA 02543.

Thompson, S.K. 1991. Adaptive cluster sampling: designs with primary and secondary units. *Biometrics* 47:1103–15.

Turnock, B.J. and Quinn, T.J. 1991. The effect of responsive movement on abundance estimation using line transect sampling. *Biometrics* 47:701–15.

Winn, H.E. 1982. A characterization of marine mammals and turtles in the Mid– and North Atlantic areas of the US outer continental shelf, Final Report. Final Report of the Cetacean and Turtle Assessment Program by the University of Rhode Island, Graduate School of Oceanography to the US Department of the Interior, Bureau of Land Management. National Technical Information Service (NTIS) Publication PB83–215855, Springfield, VA. 586pp.

Zar, J.H. 1984. *Biostatistical Analysis*. 2nd Edn. Prentice Hall Inc., New Jersey. i-xiv+718pp.

Abundance Estimate of the Gulf of Maine Harbor Porpoise

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ABSTRACT

Shipboard surveys were conducted in the summer of 1991 to estimate the abundance of harbor porpoises, *Phocoena phocoena*, in the northern Gulf of Maine and lower Bay of Fundy. The best estimate is 37,500 (95% CI: 26,600 to 86,400). The estimate is based on the independent team sighting procedure from one ship, which allowed the estimation of $g(0)$: 0.72 (SE=0.06). The abundance estimate presented is substantially higher than previous estimates for the area. This is due to the more extensive areal coverage and the inclusion of $g(0)$ into the estimate. While the statistical precision that was reported here included some sources of uncertainty, others remain to be addressed. The most important of these are the potential downward bias due to animals avoiding the vessel, the highly aggregated spatial distribution of porpoises and the largely unknown effects of heterogeneity of observers, platforms and environmental conditions.

KEYWORDS: HARBOUR PORPOISE; NORTH ATLANTIC; SURVEY-SHIP; ASSESSMENT; $g(0)$.

INTRODUCTION

There are five past surveys that estimated the abundance of harbor porpoise in the Gulf of Maine-Bay of Fundy region (Gaskin, 1977; Prescott *et al.*, 1981; Winn, 1982; Kraus *et al.*, 1983b; Gaskin *et al.*, 1985). Estimates ranged from roughly 3,000 to 15,000 animals. They provided minimum estimates of abundance because of their limited ranges and because of failures of assumptions made in the analyses. In 1991, two surveys were conducted over a much broader area using line transect survey techniques developed to overcome some of the previous methodological problems (Kraus *et al.*, 1983a; Barlow, 1988; Butterworth and Borchers, 1988; Polacheck, 1989; 1994a; b; Polacheck and Smith, 1989; 1990; Øien, 1990; Polacheck and Thorpe, 1990; Polacheck *et al.*, 1990; 1994).

In this paper, I present a new population abundance estimate using data collected during the two 1991 surveys. The reliability of the abundance estimate is assessed and potential sources of uncertainties that were not accounted for are discussed. This paper updates the abundance estimate reported in Smith *et al.* (1991), Anon. (1992) and Read *et al.* (1993).

METHODS

Field procedures

From 22 July – 31 August 1991, a shipboard sighting survey was performed in the offshore waters of the Gulf of Maine-lower Bay of Fundy-southern Scotian shelf area. From 3 – 17 August 1991 a second survey was performed in the shallow inshore bays off Maine (Fig. 1). 'Passing mode' line transect methods (Burnham *et al.*, 1980; Butterworth and Borchers, 1988) were used on both vessels. The independent team sighting procedure was used on